HUMAN MOVEMENT
2013, vol. 14 (1), 70–75

STEP AEROBICS AND RHYTHM OF MOVEMENT OF THE UPPER AND LOWER LIMBS

doi: 10.2478/humo-2013-0006

JOANNA MILEWSKA, SEBASTIAN JAROSZCZUK, ALICJA RUTKOWSKA-KUCHARSKA *
University School of Physical Education, Wrocław, Poland

ABSTRACT
Purpose. The aim of this investigation was to look for relationships between the repeatability of forces generated during the movement rhythm present in step aerobics and the movement to a rhythm by the upper and lower limbs alone. As step aerobics requires the symmetric involvement of both the upper and lower limbs, it appears to be important to examine whether a relationship exists between repeatability of a rhythm and a repeatability of forces generated when moving to a rhythm. As step aerobics is considered an endurance activity, the repeatability of the force reproduced by the lower limb muscles may be important in the prevention of injury. **Methods.** The study involved using a mock step bench which consisted of two Kistler force plates. The 29 female subjects of the study executed two motor tasks. The first task was hitting the plate with the dominant and the non-dominant upper and lower limb to a musical rhythm. The second task consisted in performing the basic step of step aerobics on the bench. The rhythm in both tasks was dictated by the beat of a metronome. **Results.** No statistically significant differences were found between respectability of producing a rhythm by the dominant and non-dominant upper and lower limbs. No correlation was found between the rhythm reproduction error of the limbs and the accuracy of moving to a rhythm during the step aerobics task. This second task was characterized by a high repeatability of the generated forces and a high variability in following a musical rhythm. **Conclusions.** Body mass does not influence the force generated during rhythm reproduction with the upper and lower limbs. During step walking, the study participants were characterized with a high repeatability of generated force and also by a high variability in following a musical rhythm.

Key words: rhythmical abilities, lateralization, step-aerobics, loads

Introduction

Step aerobics is a kind of physical activity in which the rhythm of movement is defined by an external musical rhythm. It involves a variety of movements created by using both the lower and upper limbs, where step aerobics instructors attempt to ideally keep the set of moves symmetrical and by using both left and right limbs equally. As the basic form of movement is based on a different combination of step moves, where the initiation of a step with the right lower limb is frequently paired to the usage of the left upper limb. Music is used to accompany this form of physical exercise, making it easier for its participants to adjust their rhythm of movement to the beat of the music being played. This makes it possible to easily determine the step frequency and to control the intensity of exercise to the participants' fitness level. Unlike the rhythm of movement found in sports such as figure skating and rhythmic sportive gymnastics, in which the body's movement is used to express or enhance the music being played, the rhythm found in most step aerobics classes corresponds to the most basic form of musical rhythm, i.e. body movement is rhythmically choreographed to the beats of the music It can therefore be assumed that the lower and upper limb movements performed on the basis of a musical beat are an expression of rhythmical ability.

Rhythmic ability, considered as an facet of coordination, has been a subject in fields of kinesiology. Many researchers have investigated, for example, bimanual coordination [1–3]. Others have been searching for special structures within the CNS responsible for the ability to reproduce a musical rhythm within a movement [4, 5]. In order to assess the rhythmization ability, by either studying its determinants [4, 6] or in diagnosing it for physical education [7] or for competitive sports purposes [8, 9], various tests quantifying the accuracy of movement performed in a defined time have been used.

Humans are asymmetric by nature. The problem of symmetrical movement of the upper and lower limbs has been the subject of many studies and the corresponding methodology can be traced back to the Bernstein theory [10]. Asymmetry manifests itself by a differentiation in the kinematic and kinetic parameters of the limbs during walking [11], by the muscle strengths on the right and left side of the body [12, 13] as well as by the accuracy of movements of the right and left upper limbs [14]. Research found that the ability to produce a musical rhythm with upper limbs can be characterized by being either asymmetric or symmetric [1]. This can result from the rhythm complexity or from a differentiation of its dynamics. In the case of physical activity which is subject to musical rhythm (such as aerobics, dance, skating) and comprises of symmetrical move-

* Corresponding author.

ments, it is important that its participants produce both symmetric and repeatable values of forces.

On the one hand, step aerobics helps improve the movement symmetry of the lower and upper limbs, but on the other hand, they themselves require a certain level of rhythmical ability. The ability to reproduce movement that is musically rhythmic is based on muscle control and depends directly on muscular synergism, which manifests itself, among others, in the optimization of the recruitment of agonists, antagonists and synergists in every movement cycle [15]. As such, in step aerobics, the slowing down of movement by one musical bar (measure) forces the participants to therefore speed up in the next sequence of movements. As improper synchronization of muscle activation may result in the poor damping of the ground reaction forces [16], which may lead to ankle joint injuries caused by articular capsule damage. The results of certain studies find that ankle joint injuries are one of the most frequent forms of injuries in step aerobics. The creation of an easy-to-perform test of rhytmization ability test could therefore protect less-able individuals from suffering locomotor injuries.

Therefore, the aim of this study was to find a relationship between the repeatability of the forces generated during the rhythmic stepping performed in step aerobics and the rhythmic movements executed by the upper and lower limbs alone. Since step aerobics requires the symmetric involvement of both the lower and upper limbs, it seems important to conduct research to examine whether there exists a relationship between the rhythmic repeatability and the repeatability of the forces generated when performing rhythmic movement. As step aerobics is considered an endurance activity (where an average sessions lasts 60 min), the repeatability of the forces produced by the lower limb muscles may be important in the prevention of injury.

Material and methods

The study consisted of 29 randomly selected female participants who were students at the Department of Physical Education, aged 19 to 26. Their average body height was 167.8 ± 5.77 cm and body mass was 59.2 ± 4.90 kg. The laterality of the participants' upper and lower limbs (whether they were right-handed, left-handed, right legged, left legged) was determined, based on a questionnaire [17]. Those who took part in the study had never before participated in step aerobics, nor played a musical instrument nor received any musical education. All participants were unaware of the purpose of the experiment.

Experimental stand

Data was collected at the Biomechanical Analyses Laboratory of the University School of Physical Education in Wrocław (ISO quality standards: ISO 9001:2001). A special structure (a mock step bench) was built in order to carry out this study. It consisted of two Kistler force plates (type 9282B), where one was mounted at a height 15 cm (plate A) and the other placed on the floor (B). The platforms were connected through an eight channel 9863A Kistler amplifier with a sampling frequency of (500 Hz) and an analog-to-digital converter to a computer running BioWare® 2.0 software, which was supplied by the force plate manufacturer. A digital metronome set to a frequency of 132 bpm (beats per minute) was used during the experiment.

Description of motor tasks

Each participant executed two motor tasks. The first one consisted in following the beat of the metronome with the upper and lower limbs. The participant first hit the Kistler force plate ten times with the right and left upper limbs and then with the right and left lower limb. When being tested with the upper limbs the participant was in a position as shown in Figure 1, where the opposing upper limb was positioned on the ground.

When performing the lower limb movements the participant sat in a chair (seat height of 43 cm), where the upper limbs rested on both sides of the chair (Fig. 2),

Figure 1. The experimental setup. Rhythm reproduction with the upper limb on a Kistler force plate (A)

Figure 2. The experimental setup. Rhythm reproduction with the lower limb on a Kistler force plate (B)

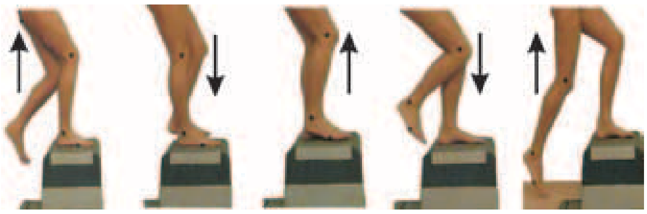


Figure 3. Basic step

with the non-tested lower limb resting freely on the ground. The participants then hit the Kistler force plate found on the ground (plate B) with the lower limb while following the beat of the metronome.

The second motor task consisted in executing ten basic steps (Fig. 3). While standing on the lower platform, the participant initiated a step with the right leg towards the upper platform in response to a cue provided by the instructor.

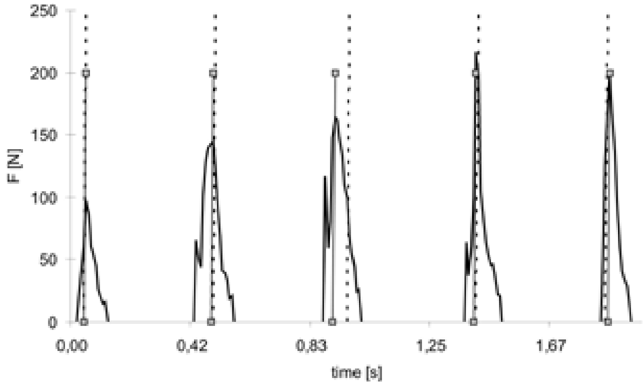
The consecutive trials were then performed with the following scheme (where RH – Right Hand, LH – Left Hand, RL – Right Leg, LL – Left Leg):

SUBJECT No. 1: RH | LH | RL | LL | basic step
SUBJECT No. 2: LL | RH | LH | RL | basic step
SUBJECT No. 3: RL | LL | RH | LH | basic step
SUBJECT No. 4: LH | RL | LL | RH | basic step
and continued with the rest of the subjects.

Data analysis

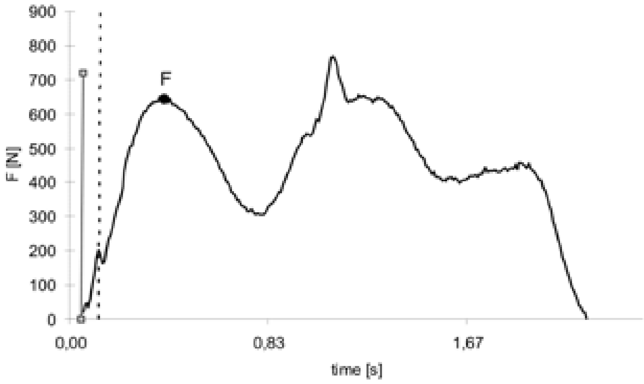
Data was analyzed using the "SMARTanalyzer" software, where two function were used to analyze the ground reaction force signal recorded during the experiment. By using a "Truncate over a threshold" function, the signal recorded was set with a cutoff of 15 N (anything below was considered noise). Then, by using the "Local max, outside stable region" function (with the parameters set at: local ray – 400 ms, amplitude std – 5%, min stable width – 100 ms), the times that corresponded with the local maximal values were found. The obtained values were then exported as text files.

For the first task (reproducing a rhythm with the upper and lower limbs), the signal was recorded as a sequence of force values at discrete time intervals, i.e., the beats of the metronome (Fig. 4). The time interval between the consecutive maximal values were compared to the intervals defined by the metronome and thus the rhythm reproduction error was evaluated. In a similar way was the rhythm reproduction error found in the second task (the basic step), with the stepping rhythm being now defined by the force impulses recorded when the foot stepped up on the platform (Fig. 5). From the data collected the maximal (vertical component) value of the ground reaction force Fmax (N) as well as the time of error (s) were estimated. Statistical analyses were performed using the Wilcoxon signed-rank test (paired difference test) and Spearman's rank correlation coefficient.



---- tap on the plate, – beat of the digital metronome

Figure 4. An example of the ground reaction force generated when hitting out the rhythm with the upper and lower limbs



---- put on the heel on the plate – beat of digital metronome

Figure 5. An example of the ground reaction forces during the basic step tasks

Results

Upper and lower limbs movement symmetry and rhythm reproduction symmetry during step

In order to state whether there is indeed symmetry found in the production of a rhythm with dominant and non-dominant limbs, the rhythm reproduction errors calculated for the upper and lower limbs were compared. No statistically significant differences were found between the dominant and non-dominant as well as upper and lower limbs. On the other hand, statistically significant differences were found between the rhythm reproduction error found when performing step and when the lower limbs tapped out the rhythm in the first task (Tab. 1).

A comparison of the minimal and maximal values of the rhythm reproduction error points to a considerable difference found among the study group, and this applies to data collected during the upper and lower limb task as well as during the basic step task. Therefore it is was considered whether the level of accuracy in reproducing rhythm with the dominant limb corresponds to the one for the non-dominant limb. It was

Table 1. Mean values and standard deviations of the musical rhythm reproduction error for the upper and lower limbs, and during the basic step

Variable	Mean ± SD (s)	Min. (s)	Max (s)
Dominant hand	0.018 ± 0.0054	0.0098	0.0309
Non-dominant hand	0.019 ± 0.0100	0.0106	0.0591
Dominant leg	0.020 ± 0.0067	0.0107	0.0415
Non-dominant leg	0.017 ± 0.0052	0.0092	0.0270
Step	0.026 ± 0.0084	0.0131	0.0506

* significant at the level of $p < 0.01$

Table 2. Spearman's correlation coefficient of the musical rhythm reproduction error between the upper and lower limbs, and the basic step

Pair of variables	*R*	*t*(*N*–2)	*p*
Dominant hand & non-dominant hand	0.2532	1.3600	0.1851
Dominant leg & non-dominant leg	0.5759	3.6601	0.001*
Step & dominant leg	0.3156	1.7279	0.0954
Step & non-dominant leg	0.1878	0.9930	0.3295

* coefficients significant at the level of $p < 0.01$

on this basis that Spearman's correlation coefficient was calculated (Tab. 2). A correlation was found between the rhythm reproduction error only for the lower limbs, which means that the rhythm reproduction accuracy for the right upper limb is not correlated with the corresponding accuracy for the left upper limb. Similarly, no correlation was found between the rhythm reproduction accuracy during step aerobics and the rhythm reproduction accuracy for the right and left lower limb.

Repeatability of generating force in rhythmic movements of the lower and upper limbs

In cyclic movements of constant rhythm, the repeatability of an individual cycle duration is dependent upon the smooth transition between the concentric and eccentric activity of agonist and antagonist muscles that are responsible for such movement. This results in both the repeatability of the durations of consecutive cycles and the repeatability of the force generated by the muscles. Based on standard deviations and minimal and maximal values it can be stated that the study participants were found with a low repeatability of the recorded ground reaction forces values. It is interesting to note that higher, although not statistically significant, values were found for the dominant limb as well as both right and left ones (Tab. 3).

Table 3. Ground reaction forces (*N*) during rhythm reproduction

Variable	Mean ± SD (*N*)	Min. (*N*)	Max (*N*)
Dominant hand	77.4 ± 64.98	15.57	381.48
Non-dominant hand	67.3 ± 29.92	14.22	146.70
Dominant leg	239.6 ± 104.38	69.66	535.03
Non-dominant leg	227.7 ± 114.53	69.45	575.28
Step	617.1 ± 72.11	505.14	839.22

Table 4. Correlation coefficients between the forces generated by the dominant and non-dominant limbs, the ground reaction force during step, and the body mass of participants

Pair of variables	*R*	*t*(*N*–2)	*p*
Dominant hand & non-dominant hand	0.7980	6.8811	0.0000*
Dominant leg & non-dominant leg	0.6271	4.1832	0.0003*
Step & dominant leg	0.2291	1.2229	0.23192
Step & non-dominant leg	0.2838	1.5378	0.13574
Body mass & dominant hand	0.0470	0.2444	0.80874
Body mass & non-dominant hand	–0.0427	–0.2225	0.82558
Body mass & dominant leg	–0.0067	–0.0347	0.97257
Body mass & non-dominant leg	0.0579	0.3012	0.76556
Body mass & step	0.46921	2.7609	0.0102*

* coefficients significant at the level of $p < 0.01$

The Spearman correlation coefficient found between the ground reaction forces recorded during the rhythmic movement of the dominant and non-dominant limbs and during the step task suggests a relationship between the dominant and non-dominant limbs. This means that in individuals who obtained high ground reaction forces values when using their dominant limb to follow. This means that in individuals who obtained high ground reaction force values when using their dominant limb to follow rhythm, whether the upper or lower limb, they attain similar values of force for their non-dominant limb. No correlation was found between the body mass of the participants and the ground reaction forces produced with the upper or lower limbs when hitting out to a rhythm, but there was a correlation between the body mass and the ground reaction forces during step aerobics (Tab. 4).

Table 5. Coefficient of variability of force and rhythm reproduction error during step

Pair of variables	Force	Rhythm reproduction error	*R*	*t*(*N*–2)	*p*
Force and rhythm reproduction error	4.2 ± 0.95	90.6 ± 22.00	0.333	1.8323	0.0779

The next problem which was considered in this study was the search for a relationship between the force generated during step and the rhythm reproduction error. The ground reaction force variability index calculated for each participant during step was correlated with the rhythm reproduction error index (Tab. 5). Both a high individual repeatability of ground reaction forces and high individual variability of the rhythm reproduction error were found.

Discussion

The basic step (stepping on and then off the step bench) in step aerobics is the most common form of movement for beginners of step aerobics. It is accompanied by music in which every beat is paired with a movement of the right or left limb. Most often the movement of the right lower limb is accompanied by a movement of the left upper limb, which requires a fairly high level of movement coordination by its participants. Hence, the reason for studying whether there is symmetry in the rhythmic movement of the right and left limbs, and whether there exists a relationship between the accuracy of movement during step aerobics and accuracy of movement of just a single limb. Many authors found asymmetry between the right and left side of the body (specifically, the limbs) in terms of accuracy of movement, structure of movement, maximal torque [18]. In contrast, Barral and Debu [6] found the same movement accuracy in the right and left hand of a group of studied women. In the research presented here, no statistically significant differences in the repeatability of rhythmic movement were found between the dominant and the non-dominant as well as upper and lower limbs. The existence of a correlation in the rhythm reproduction error between the limbs of the right and left sides of the body leads to the conclusion that if someone has considerable rhythm reproduction error in one limb then they would equally move as poorly to the rhythm with the other limb. It can therefore be assumed that, for a given individual, a particular level of rhythmization ability of the dominant limb corresponds to a similar rhythmization ability level of the non-dominant limb. The lack of difference found between the limbs may be implied by the fact that moving to a rhythm in cyclical movements is much easier than in acyclical movements [19]. It could be that this occurrence of lateralization manifests itself only in extreme conditions, i.e. when a movement must be executed at a high velocity, which has been found in research cited in Olex-Zarychta and Juras [6]. Moreover, in the cited studies, the accuracy was assessed for a movement executed at an imposed rhythm. The research found here focused on the time structure and not on the spatial structure of movement.

The second issue considered in this paper was the symmetry/asymmetry of the forces generated in cyclical movements. We did not find statistically significant differences in asymmetry of force generated by the upper and lower limbs. It was found that the dominant and the non-dominant limbs produce similar values of forces. The occurrence of such dynamic lateralization in the production of force by the right or left upper and lower limb, or of the symmetric trunk muscles was described by many authors, which was collected during maximal voluntary contraction or at maximal velocity of movement [20]. In addition, a lot of information on the asymmetry/symmetry of movements between the right and left upper limb can be found in studies that investigated bimanual coordination. Riley et al. [1] found that functional asymmetry is reliably evident in a task that requires no spatial or temporal distinctions in the behaviors of the two hands. Murian et al. [21] found that loading resistance and trial duration degraded bimanual coordination patterns. Jeka and Kelso [22] showed how the symmetry of coordinative dynamics between a human arm and leg is influenced by adding inertial mass to an individual limb. They found that loading the leg was intended to enhance the asymmetry, whereas loading the hand was meant to decrease asymmetry.

Another issue considered in this study was the relationship between the force generated during step aerobics and the rhythm reproduction error (within the scope of injury prevention). It was assumed that an error free reproduction of rhythm is a result of muscle control, which manifests itself in optimization of forces produced by agonist, antagonist and synergist muscles, and in optimization of recruitment times. That is why it was expected that those participants characterized by a lower variability of force generation during step aerobics would move to a musical rhythm more accurately. What was found in this study is that the participants were characterized by a high repeatability of force generation and a very high variability of musical rhythm reproduction. As rhythmization ability is a dependent upon neuromuscular control, it was possible to infer that there is a correlation between the accuracy of rhythm reproduction with the limbs (e.g. the upper limbs) and the accuracy of moving to musical rhythm during step aerobics. Finding such a correlation would allow for the use of a simple tapping test with an imposed rhythm for individuals interested in exercising at fitness clubs, and to therefore adapt the form of exercises to the abilities of the participants, thereby limiting the incidence of injuries.

Conclusions

1. No asymmetry was found in both the accuracy of reproduction of an imposed rhythm and in the values of the generated forces between the dominant and the non-dominant limbs (both upper and lower limbs).

2. Body mass does not influence the force generated during rhythm reproduction with the upper and lower limbs.

3. There exists a relationship between the force generated by the dominant limb and the one generated by the non-dominant limb.

4. During step walking, the study participants were characterized with a high repeatability of generated force and also by a high variability in following a musical rhythm.

References

1. Riley M.A., Amazeen E.L., Amazeen P.G., Treffner P.J., Turvey M.T., Effect of temporal scaling and attention on the asymmetrical dynamics of bimanual coordination. *Motor Control*, 1997, 1 (3), 263–283.
2. Verheul M.H.G., Geuze R.H., Bimanual coordination and musical experience: the role of intrinsic dynamics and behavioral information. *Motor Control*, 2004, 8 (3), 270–291.
3. Torre K., Balasubramaniam R., Two different processes for sensorimotor synchronization in continuous and discontinuous rhythmic movements. *Exp Brain Res*, 2009, 199 (2), 157–166, doi: 10.1007/s00221-009-1991-2.
4. Trainor L.J., Gao X., Lei J., Lehtovaara K., Harris L.R., The primal role of the vestibular system in determining musical rhythm. *Cortex*, 2009, 45 (1), 35–43, doi: 10.1016/j.cortex.2007.10.014.
5. Lo Y.L., Zhang H.H., Wang C.C., Chin Z.Y., Fook-Chong S., Gabriel C., Guan C.T., Correlation of near-infrared spectroscopy and transcranial magnetic stimulation of the motor cortex in overt reading and musical tasks. *Motor Control*, 2009, 13 (1), 84–99.
6. Olex-Zarychta D., Juras G., Differences in some aspects of co-ordination between the twin and single-born subjects. *J Hum Kinet*, 2007, 17, 63–74.
7. Raczek J., Juras G., Waśkiewicz Z., The diagnosis of motor coordination. *J Hum Kinet*, 2002, 6, 113–125.
8. Mehlich R., Iskra J., Góralczyk R., Waśkiewicz Z., Specific and non-specific timing abilities of elite Polish hurdlers. *J Hum Kinet*, 2002, 8, 93–98.
9. Zachopoulou A., Mantis K., Serbezis V., Teodosiou A., Papadimitriou K., Differentiation of parameters for rhythmic ability among young tennis players, basketball players and swimmers. *Physical Education and Sport Pedagogy*, 2000, 5 (2), 220–230, doi: 10.1080/1740898000050208.
10. Petryński W., Bernstein's construction of movement model and contemporary motor control and motor learning theories. *Hum Mov*, 2007, 8 (2), 136–146.
11. Winiarski S., Rutkowska-Kucharska A., Estimated ground reaction force in normal and pathological gait. *Acta Bioeng Biomech*, 2009, 11 (1), 53–60.
12. Rutkowska-Kucharska A., Szpala A., Pieciuk E., Symmetry of muscle activity during abdominal exercises. *Acta Bioeng Biomech*, 2009, 11 (1), 25–30.
13. Szpala A., Rutkowska-Kucharska A., Drapała J., Buczkowski K., Zawadzki J., Electromechanical delay (EMD) in symmetrical activity of the muscles stabilizing spinal column under static conditions. *Acta Bioeng Biomech*, 2010, 12 (4), 11–18.
14. Jaszczak M., The dynamical asymmetry of the upper extremities during symmetrical exercises. *Hum Mov*, 2008, 9 (2), 116–120, doi: 10.2478/v10038-008-0014-7.
15. de Freitas P.B., Krishnan V., Jaric S., Force coordination in object manipulation. *J Hum Kinet*, 2008, 20, 37–51, doi: 10.2478/v10078-008-0016-8.
16. Williford H.N., Richards L.A., Scharff-Olson M., Brown B., Blessing D.L., Duey W.J., Bench stepping and running in woman. Changes in fitness and injury status. *J Sports Med Phys Fitness*, 1998, 38 (3), 221–226.
17. Osiński W., Kinesiology [in Polish]. AWF, Poznań 2003.
18. Starosta W., Lateral differentiation of movement in light of N. Bernstein's theory. *J Hum Kinet*, 2000, 3, 3–15.
19. Raczek J., Mynarski W., Ljach W., Ljach W., Theoretical and empirical basis for developing and diagnosing of coordination motor abilities. AWF, Katowice 1998, 36–98.
20. Szpala A., Rutkowska-Kucharska A., Drapała J., Buczkowski K., Choosing the right body position for assessing trunk flexors and extensors torque output. *Hum Mov*, 2011, 12 (1), 57–64, doi: 10.2478/v10038-011-0005-y.
21. Murian A., Deschamps T., Temprado J.J., Effects of force production and trial duration on bimanual performance and attentional demands in a rhythmic coordination task. *Motor Control*, 2008, 12 (1), 21–37.
22. Jeka J.J., Kelso J.A.S., Manipulating symmetry in the coordination dynamics of human movement. *J Exp Psychol Gen*, 1995, 21 (2), 260–374, doi: 10.1037/0096-1523.21.2.360.

Paper received by the Editors: June 11, 2012
Paper accepted for publication: December 7, 2012

Correspondence address
Alicja Rutkowska-Kucharska
Katedra Biomechaniki
Akademia Wychowania Fizycznego
al. I.J. Paderewskiego 35
51-612 Wrocław, Poland
e-mail: alicja.rutkowska-kucharska@awf.wroc.pl